A SYNTHENIC CONTROLER METHOD BASED ON THE INTERNAL MODEL PREDICTIVE COTROL FOR NONLINEAR TIME DELAY SYSTEMS

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SUMMARY

The existence of uncertain factors makes model predictive control problem become truly difficult because of the complexity of online linear optimal problem and the processing of uncertain factors must be processed simultaneously. With uncertain nonlinear time delay objects, the mentioned complexity has to be involed the complexity due to time delay. Because of the wide spread of time delay objects in industry and strict requirements of increasing the control quality, finding the predictive control methods for this class becomes an essential problem recently. In order to deal with the above problem, the article focused on the study: Predictive control for the class of objects containing uncertain nonlinear, time delay

Từ khoá: *Model predictive control, internal model predictive control, disturbance, nonlinear, time delay systems*

INTRODUCTION

The dissertation focused on researching, and suggestting predictive control method for a class of nonlinear time delay systems based on the foundation of disturbance identification using neural network. This nonlinear system is represented by a linear system plus uncertain nonlinear component which classified as uncertain disturbances or endogenic disturbances, measureless, state-dependent and cannot be modeled [1], [2].

First and foremost, we have to identify disturbances affecting to system using weight updated law based on Radial Basic Function (RBF) online. When the identification of disturbances completed with optional accuracy, it is possible to reject disturbance or compensate disturbance effects. Hence, the control problem becomes easier because the system will be a time-delay linear with certain parameters then we are able to generate MPC (Model Predictive Controller) [3], [4], [5]. As it can be seen, MPC is a well-known method for time-delay system. The means of MPC for time-delay linear which have been developed in recent years has reached certain results.

However, a difficulty when MPC is applied in reality is that the controller always has to solve online optimal problem, optimal controlling signal is estimated only for continuous point, therefore, hardware must handle a lots of calculation. Sometimes, it is impossible to ensure real time or it would be unstable if there is no root for optimal problem, or taking much of time to calculate because of strict constrain conditions. Finding new methods in order to deal with the provided difficulties is an urgent task [5], [6].

THE OVERVIEW OF RESEARCH

Overview of Model Predictive Control (MPC)

Model Predictive Control is a system control method based on the outputs of objects which are predicted through a mathematical model. Based on output predictive signal of object, optimal algorithms are used to find optimal control signal so that the future output of object tracks the desired value. Thus, this optimal control signal depends on the accuracy of output predictive signal of object and the algorithm to find optimal roots. In reality, mathematical model of object is usually established based on physical theorems which are complex and normally inaccurate. Therefore, introducing a method to identification or establishing model of object accurately is interesting many scientists and researchers [1],[5].

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Research proposal and solution in the article

Instead of designing predictive controller for time-delay dependent nonlinear system, we design the predictive control for linear system accompanies with disturbances (uncertain nonlinear-state dependent disturbances). This disturbance component is identified online and will be compensated to make the system to be a time-delay linear system. Then, we use internal model predictive control method based on disturbance identification to guarantee the stability and find ranges of prediction and control.

Synthesizing predictive control system for uncertain nonlinear systems with time-delay is divided into following contents:

Separating nonlinear system model into 2 parts: time-delay linear component and nonlinear component. According to the linearization at the operating point, we easily determine kinetic parameters of the system through matrices A and B based on nominal working point, the remaining nonlinear component is considered as state dependent disturbances or endogenic disturbances of the linear model.

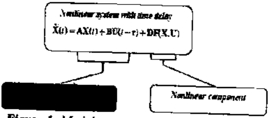

Figure 1. *Model structure of class of time-delay nonlinear objects*

- Using artificial neural network RBF (simple network and easy training) to online identify uncertain nonlinear component of the plant;
- Compensating disturbances based on results of identification;
- Establishing internal model state feedback predictive controller with the structure of compensated disturbance to control the plant which containing only time-delay linear component.

DISTURBANCE IDENTIFICATION ALGORITHM OF TIME-DELAY SYSTEMS BASED ON THE USING OF THE RBF NEURAL NETWORK

Establishing identification algorithm

$$\dot{\mathbf{X}}(t) = \mathbf{AX}(t) + \mathbf{BU}(t-\tau) + \mathbf{DF}(\mathbf{X},\mathbf{U}) \qquad (1)$$

Based on [7], [8] we have structure diagram of neural network approximating as Figure 2.

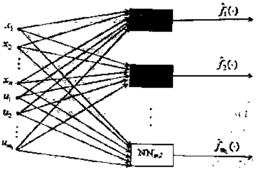

Figure 2. *Structure diagram of neural network approximating functions* $f_1(\cdot), f_2(\cdot), \cdots, f_{m_2}(\cdot)$ *of system (1)*

$$\dot{\mathbf{E}}(t) = \mathbf{AE}(t) + \mathbf{D}\tilde{\mathbf{F}}(\mathbf{X},\mathbf{U}) \qquad (2)$$

The sufficient condition for the system (2) being stable is expressed in the below theorem.

Theorem: Assuming that A is Hurwitz matrix. System (2) will be real stable when the following conditions are satisfied:

$$-\mathbf{Q} + \lambda \mathbf{P}\mathbf{U}^2_{max} \le 0;$$

$$\|\mathbf{E}(t)\| \ge \frac{2\sum_{i=1}^{m_2}\varepsilon_i^*\left\|\overline{\mathbf{P}}_{n-m_2+i}\right\|}{r_{min}(\mathbf{Q})}\lambda_0;$$

$$\dot{\hat{w}}_{ij} = \lambda\phi_{ij}(\mathbf{X})\overline{\mathbf{P}}_{n-m_2+i}\mathbf{E}(t)\left[\frac{1}{\lambda} + \int_{t-\tau}^{t}\mathbf{U}^T(\xi)\mathbf{U}(\xi)d\xi\right];$$

$$i = 1,2,\cdots,m_2;\ j = 1,2,\cdots,l \qquad (3)$$

where $\mathbf{Q}$ is positive definite symmetric matrix; where $\mathbf{P}$ is positive infinitive symmetric roots of

$-\mathbf{Q} = \mathbf{A}^T\mathbf{P} + \mathbf{PA}$; $r_{min}(\mathbf{Q})$ is the smallest eigenvalue of matrix $\mathbf{Q}$; $\overline{\mathbf{P}}_{n-m_2+i}$ is row no. $n - m_2 + i$ of matrix $\mathbf{P}$;

$\mathbf{U}_{max} = \sup_t|\mathbf{U}(t)|$; $\lambda_0 = 1 + \lambda\tau\mathbf{U}^2_{max}$

Prove: The theorem has been proved tightly based on the second method of Lyapunov for system (2), where function Lyapunov is formed:

$$V = E^T(t)PE(t) + 2E^T(t)PE(t)\int_{t-\tau}^{t} U^T(\xi)U(\xi)d\xi + \sum_{i=1}^{m}\sum_{j=1}^{l}\tilde{w}_{ij}^2 \quad (4)$$

The derivation of V along the locus of (2) being always negative will be the sufficient condition for (2) being stable. Modifying $\dot{V}$, we obtain those conditions, the results are shown in (3).

Determine the corresponding conditions for disturbance compensating in time-delay dependent system with multiple disturbance affecting

The corresponding conditions which are able to compensate disturbance have been determined. It can be defined as [9]: $\mathbf{BG} = \mathbf{D}$ (5)

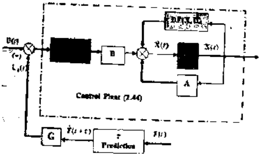

Figure 3. *Structure diagram of time-delay object in control channel, affecting by state dependent disturbance and disturbance compensation channel based on disturbance identification*

Synthesizing predictive controller based on internal model for time-delay object and establishing control system

Control object will be described by:

$$\dot{\mathbf{X}}(t) = \mathbf{AX}(t) + \mathbf{BV}(t) \quad (6)$$

$$\mathbf{V}(t) = \mathbf{U}(t-\tau) \quad (7)$$

The mentioned problem is synthesizing control system, ensuring the minimum of objective function **J** [10]:

$$J = \int_{t_0}^{t_f} H(\mathbf{X}, \mathbf{U})dt \to \min \quad (8)$$

The optimal control law follows the optimal objective (8) for the object which formed:

$$\mathbf{U}_{op}(t) = -\mathbf{K}\Psi(\tau)\mathbf{X}(t) - \mathbf{K}\int_{t-\tau}^{t}\Psi(t-\xi)\mathbf{BU}(\xi)d\xi$$

$$= -\mathbf{K}\Psi(\tau)\mathbf{X}(t) + \mathbf{K}\left\{\int_{0}^{t-\tau}\Psi(t-\xi)\mathbf{BU}(\xi)d\xi - \int_{0}^{t}\Psi(t-\xi)\mathbf{BU}(\xi)d\xi\right\} \quad (9)$$

The first component in the bracket is state vector of time-delay system τ, since control signal $\mathbf{U}(t)$ creating during the time from 0 to $t-\tau: [0, t-\tau]$; the second one in the bracket is state of system without time-delay since the control action $\mathbf{U}(t)$ creating during the time from 0 to t: $[0, t]$. These components are easy to create of models:

$$\dot{\mathbf{X}}_{M_1}(t) = \mathbf{A}_M\mathbf{X}_{M_1}(t) + \mathbf{B}_M\mathbf{U}_M(t-\tau) \quad (10)$$

$$\dot{\mathbf{X}}_{M_2}(t) = \mathbf{A}_M\mathbf{X}_{M_2}(t) + \mathbf{B}_M\mathbf{U}_M(t) \quad (11)$$

$$\mathbf{U}_{op}(t) = -\mathbf{K}\Psi(\tau)\mathbf{X}(t) - \mathbf{KX}_{M_2}(t) + \mathbf{KX}_{M_1}(t) \quad (12)$$

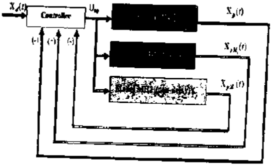

Figure 4. *Structure diagram of control system based on predictive model for a class of time-delay dependent objects*

It is clear that model $\mathbf{M_2}$ implements predictive predictions of the object's state vector with prediction time τ in the condition without delay and $\mathbf{A}_M = \mathbf{A}; \mathbf{B}_M = \mathbf{B}$, we have: $\mathbf{X}_{M_2}(t) = \mathbf{X}(t+\tau)$ (13)

Thus, the system's predictive sash is $[t, t+\tau]$. This sash will slide following the time axis during operating. From (12) and (13), we can clearly see that the affection of optimal control (12) is created based on the foundation of predictive results (13), the state vector of control object X(t) and state vector of model $\mathbf{MH_1}$ with delay $\mathbf{X}_{M_1}(t)$. Therefore, the control range will be τ. The optimal control function (12) which gained is analytical function of system's state vector

$\mathbf{X}(t)$, the state vector of model $\mathbf{MH}_1$ with time-delay $\mathbf{X}_{M_1}(t)$ and state vector of predictive control $\mathbf{MH}_2$ without time-delay $\mathbf{X}_{M_2}(t)$ at the time t.

However, control laws (12) are only able to apply in cases matrices **A** and **B** having invariable components and control objects (6), (7) are not affected by disturbance [11]. It is able to apply control laws (12) for the cases which exists state dependent disturbance, we can use identification methods and disturbance compensation based on predictive model as suggested in Part 2. Hence, the combination between control law synthesized method based on suggested predictive model and identification method and compensated disturbances affecting to object, we will have solution to solve completely control problem based on predictive control for a very wide class of time-delay dependent object under effects of disturbance, especially uncertain nonlinear disturbance depends on state.

The obtained control law is analytic function of state vector of control object, state vector of time-delay dependent model, make sure both optimal and stable characteristic for system. The calculation to define optimal control value $\mathbf{U}_{op}(t)$ following control law which gained in (12) is very simple with only three multiplications and one addition without the essential of finding solutions for differential equation Riccati with two boundary conditions like the situation tf is finite. Therefore, calculation the real time accompanying with realizable characteristic of control law are guaranteed.

Simulation

Establishing IMPC to control two channel C_b and h together with two input control signals of CSTR [12].

In this case, after disturbance is compensated $f_1(\bar{h})$ and $f_2(\bar{h},\bar{C}_b,\bar{u}_1,\bar{u}_2)$, the kinematic equation of object CSTR formed:

$$\begin{cases}\dot{\bar{h}} = a_{11}\bar{h}(t) + b_{11}\bar{u}_1(t-\tau) + b_{12}\bar{u}_2(t-\tau)\\ \dot{\bar{C}}_b = a_{21}\bar{h}(t) + a_{22}\bar{C}_b(t) + b_{21}\bar{u}_1(t-\tau) + b_{22}\bar{u}_2(t-\tau)\end{cases} \qquad (14)$$

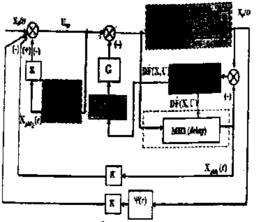

Figure 5. *Structure diagram of control system based on internal predictive model for time-delay dependent object basing identification by neural network including disturbance compensating*

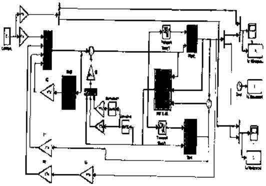

Figure 6. *Structure diagram of 2-channel control for liquid level h and concentration Cb using 2 control signal following IMPC structure*

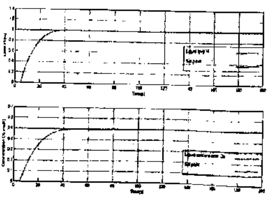

Figure 7. *Response of liquid level and concentration Cb using IMPC controller employing 2 control signals for time-delay dependent object* $\tau = 5s$

From Figure 5. applying on CSTR case get Figure 6. The results on Figure 7. indicate that there is no overshoot and the steady error equals to zero, although the time-delay $\tau = 5s$ exists.

CONCLUSION

Model predictive control has many significant advantages, high efficiency for time-delay dependent objects, slow kinematic objects and objects with constrains. Predictive control keeps improving remarkable in recent decades and reached important achievements; however, there are many essential problems which has not been solved or unsatisfactory. One of those is establishing method to synthetize predictive control system for uncertain (or a part is uncertain) nonlinear object affecting by disturbance and time-delay effect. This class is popular in industry and desired for higher quality control and more effective.

Therefore, the above mentioned problem becomes more and more urgent in both scientific side and application in reality.

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TÓM TẮT

MỘT PHƯƠNG PHÁP TỔNG HỢP BỘ ĐIỀU KHIỂN DỰA TRÊN CƠ SỞ ĐIỀU KHIỂN DỰ BÁO THEO MÔ HÌNH NỘI CHO HỆ THỐNG PHI TUYẾN CÓ TRỄ

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Việc tồn tại các yếu tố bất định làm cho vấn đề điều khiển dự báo theo mô hình (MPC – Model Predictive Control) thực sự trở nên khó khăn bởi đồng thời phải xử lý tính phức tạp của bài toán tối ưu phi tuyến trực tuyến và xử lý các yếu tố bất định. Với các đối tượng phi tuyến bất định có trễ, độ phức tạp nêu trên còn được cộng thêm phần trở ngại do hiệu ứng trễ gây ra. Mặt khác, các đối tượng có trễ này rất phổ biến trong công nghiệp, các yêu cầu nâng cao chất lượng điều khiển ngày càng cao, dẫn đến việc xây dựng các phương pháp điều khiển dự báo cho lớp đối tượng này ngày càng trở nên cấp thiết. Nhằm góp phần giải quyết khó khăn này, bài báo đặt vấn đề nghiên cứu về điều khiển dự báo cho lớp đối tượng với thành phần phi tuyến bất định, có trễ.

Từ khóa: *Điều khiển dự báo, điều khiển dự báo theo mô hình nội, nhiễu, phi tuyến, hệ có trễ*

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